DEVELOPMENT OF ACID RESISTANT BRICKS USING WASTE MATERIALS

A THESIS IN THE PARTIAL FULFILLMENT OF THE REQUIREMENTS FOR THE DEGREE OF BACHELOR OF TECHNOLOGY

BY

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CERTIFICATE

This is to certify that the thesis entitled, ***"Development of Acid Resistant Bricks Using Waste Materials"*** submitted by Mr. PRATEIK MAHAPATRA in the partial fulfilment of the requirements of the award of Bachelor of Technology Degree in Ceramic Engineering at the National Institute of Technology, Rourkela is an authentic work carried out by him under my supervision and guidance.

To the best of my knowledge, the matter embodied in the thesis has not been submitted to any other university / institute for the award of any Degree or Diploma.

13/5/13

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Thanking You,

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ABSTRACT

The disposal of industrial wastes comprises one of the major worldwide environmental problems as these wastes render the environment unfriendly. The growing demand for waste utilization has made solid wastes like materials from granite processing industry, and blast furnace slag to be absorbed into the ceramic composition of bricks. The possibility of reduction of the production costs provides a strong logic for use of this waste.

Blast furnace slag is a non-metallic by-product from ironand steel industry which is generated during the conversion ofiron ore or scarp iron to steel, along with coke for fuel. Presence of hazardous elements such as Pb, Cd, Ni and Cr are common in some steel slags which make the slag environmentally harmful.

In this work, attempt has been made to develop Acid Resistant Bricks from waste materials i.e. granite saw dust derived during cutting and grinding of granite blocks and blast furnace slag along with clay. The different body formulations have been made in order to study the effect of these three raw materials on the fired properties of the acid resistant bricks. The body made with the variation of raw materials have been fired at three different temperatures and their behaviours with respect to Apparent Porosity, Water Absorption, Bulk Density and Firing Volume Changes as a function of both temperature and granite:slag ratio was studied. It has been observed that the vitrificationof the body increased with the increase in granite content. This increase is attributed to the increase in Feldpar content which accompanies the increase of granite.

CHAPTER 1
INTRODUCTION

The disposal of industrial wastes comprises one of the major worldwide environmental problems. In numerous countries,the limitation of number of dumping landfill sites and the general disposal methods has rendered the environment unfriendly. Furthermore, as aconsequence of environmental and financial considerations, there is a growing clamour for wastes to be re-used or recycled. Waste recycling, generated by the industries, as an alternative to raw materials is not a new thing and has been carried out successfully. The prime focus on waste material utilisation is due to the exhaustion of the natural resources, the conservation of not renewable resources,and reduction in wastes disposal costs.

Solid wastes, such as the wastes from the granite industry can be absorbed by the construction industry which is listed as the mosttechnologically active sector.Large quantity of raw materials is used by the sector as well as by the large volume of final products is used in construction. The use of wastesas an alternative to raw materials in the ceramic industry, which embodies part of the construction industry, contributes to the diversification of raw materials in the production of ceramic bricks and tiles and reduces the costs in a building.

The most promising business areas of the mining sector are the Granite mining and process industry, with a mean growth in the world production reported at 6% per year in the last 10 years. The international trading is approximately US$ 6 billion per year and around US$ 13 billion, taking into account tools, equipment, etc.Generationof large amount of wastes in the industrial sector is in the form of a mud which is basically composed of SiO_2, Al_2O_3, F_2O_3 and CaO, due to the sawing and polishing processes, can cause serious damages to the environment, such as soil and underground water contamination, if not efficiently treated before disposal.

The recycling of granite wastes in the ceramic industry has attracted technological attention in the last years due to the possibility of reduction of the production costs, use of residues as a secondary raw material in the production of very stable glassy phases (glass and glass‑ceramic industry), and by the opportunity in overcoming some problems in the production of bricks and tiles with the incorporation of granite sawing wastes in their formulations. Reproducibility of the chemical composition and particle size distribution of these wastes have benefitted the above mentioned facts.Works concerning the use of granite wastes in the fabrication of glasses and glass‑ceramics,porcelainized bodies and production of bricks and roof tiles have also been published.

The present utilization of blast-furnace slags is anurgent environmental and ecological demand. The increase in the annual accumulation of thesepollutants has made the situation more demanding and pressing.Blast furnace slag is a non-metallic by-product from ironand steel industry. The generation of blast furnace slag takes place during the conversion ofiron ore or scarp iron to steel, along with coke for fuel. Productionof one tonne of steel leads to the manufacturing of500‑700 kg of slags. The molten slag comprises about20% by mass of iron production. Presence of hazardous elements such as Pb, Cd, Ni and Cr are common in some steel slags. Different forms of Slag products vary according to the method used in cooling the molten slag. These products rangefrom air-cooled blast furnace slag to expanded or foamed slag to palletized slag, to granulated blast furnace slag. The study concentrates on granulated blast furnace slag,which is cooled and solidified by rapid water quenchingto a glassy state with little or no crystallization. Many solutions have been proposed for the technical treatment of theblast furnace slag in variable fields and industries such as concrete works, steel corrosion prevention, reductionof alkali silica reactivity, cement industry, road constructions, clay brick production and ceramic field.

The use of wastes after detecting their potentialities is considered today as an activity that can contribute to the diversification of products, decrease of final costs, besides providing alternative raw materials to a series of industrial sectors.

Chapter 2 gives a brief survey on the literatures studied, to facilitate the development of Acid Resistant Bricks using waste materials.Chapter 3 lists out the objective of the present study in a nut shell. Chapter 4 details the experimental techniques adopted in the present study. Chapter 5 discusses the results obtained by the series of experiments and attempts to make a discussion out of the results.Chapter 6 concludes the observations of the present work and suggests few possibility of future work could be undertaken.

CHAPTER 2
LITERATURE REVIEW

Acid resistant sewage bricks have been studied by ***Ibrahim et.al. [1]***, wherein local Egyptian siliceous plastic clay along with granite processing waste(dust) were used as the starting rawmaterials.It has been mentioned that the standard Egyptian acid resistance bricks should have a cold crushing strength greater than 30 MPa and weight loss less than 3.5% in an acid solution. Attempt has been made to study the properties of acid resistant bricks with and without addition of potash feldspar along with the above mentioned raw materials. It has been reported that the sintering of the brick occurs in the temperature range 1100- 1175^{0}C due to the formation of low melting phases in the above temperature. Microstructural study and the analysis of the sintered brick suggested formation of Neogenic feldspar minerals in the structure. This Neogenic feldspar formation has been correlated with the fine granite waste present in the body, which lowered the temperature of formation of liquid phase and the viscosity. It has been reported that cold crushing strength of the bodies were relatively high in the range 74 - 124 MPa and the bodies also exhibited high resistance to the attack by acids (weight loss in the range between 0.22 and 0.64%). The values obtained were in conformity to the Egyptian standards. Bricks prepared along with potash feldspar (5 to 10%) showed increased values of strength and acid resistance, which were correlated with the increase in Na+ ions in the structure.

The waste materials, in the form of granite sawing wastes, lead to pollution and damaging of the environment. ***Menezeset.al [2]*** studied the characterization of ceramic bricks and tiles, wherein granite sawing wastes from the process industries in Paraiba State, Brazil had been used as an alternative to the ceramic raw materials. Studies has been conducted on density, particle size distribution, surface area (BET), chemical composition, thermal analysis (DTA and TGA), phase analysis (XRD), and microstructural analysis (SEM) of the above mentioned waste to determine its suitability of use.It has been reported that the physical and mineralogical characteristics of granite wastes were similar to the conventional ceramic raw materials. The work, reportedly produced bricks and tiles which comprised of waste materials and ceramic raw materials. It was concluded that the technological characteristics of the Brazilian standards were met by the ceramic bodies.

Bricks resistible to the action of chemicalswere studied by ***Medhat S. El-Mahllawy [3]***, wherein kaolin fine quarry residue (KFQR), the granulated blast-furnaceslag (GBFS) and granite‑basalt fine quarry residue (GBFQR) were used as raw materials. The study mainly concentrated on making bricks resistible to sewage waters, and possessing better properties than the conventional brick. It has been mentioned that the characterization of the fired specimens was done with respect to the Egyptian Standard Specification (ES 41-1986), which required the Acid Resisting Brick (ARB) to have a water absorption <6%, Acid weight loss <3.5% in an acid solution and Cold crushing strength >300 kg/cm^2. Attempt has been made to study the properties of the bricks with composition KFQR (constant at 50%), GBFQR (increasing from 10 to 40%) with decreasing values for GBFS (decreasing from 40 to 10%). The work carried out the characterization of the chemical and mineralogical properties by X-Ray Fluoroscence and X-Ray diffraction techniques respectively.It has been reported that the firing of the samples was carried out between 1100 - 1175^0C with the firing rate fixed at 5^0C/min and the soaking time set at 4 hours. The Bulk Density, Volume Changes and Firing weight Loss of the solid briquette were reported. The different batches were studied and it was observed that ceramic properties were significantly harmed if the percentage of GBFQR is increased above 25%. This can be correlated to the presence of excess feldspar from the granite which forms large amounts of low melting phases. It was concluded that the batch containing 50% KFQR, 20% GBFQR and 30% GBFS and fired at 1125^0C and exhibited the requisite ceramic properties and was in conformity to the Egyptian standards for Acid Resistant Bricks.

D Eliche-Quesada et.al [4]studied the bricks which were produced by blending various industrial wastes with clay. Attempt to investigate the influence of the waste addition on the properties of the bricks like bulk density, water absorption and linear shrinkage as well as the thermal and mechanical properties was made. The waste matter used included urban sewage sludge, bagasse, Olive mill wastewater, coffee ground residue and sludge from the brewing industry. The composition of clay and waste were characterized by Chemical elemental analysis, X-ray Diffraction, X-Ray fluorescence Differential Thermal Analysis and Thermo Gravimetric analysis. Clay along with an optimal proportion of waste was used to manufacture the bricks. It was observed that the values obtained for water absorption increased to greater than 35% and the thermal insulation values had an increase of at least 8% when wastes like brewing industry sludge, urban sewage sludge and bagasse were incorporated into the body. On the other handthe reported compressive strength of the body decreased by a maximum of 19%.Further studies concluded that on incorporation of coffee grounds and olive mill wastewater of clay the compressive strength of bricks was similar to that of bricks without waste and 19% improvementin thermal conductivity was observed. Microstructural Analysis and water absorption values suggested that the changes in results were due to the quantity and type of waste used resulting in change in the type of porosity formed.

Investigationswere carried out by ***SK Malhotra et.al [5]***into the development of bricks from granulated blast furnace slag, a by-product of the iron and steel industry. In the study it has been suggested that by pressing slag-lime mixture and sand mix at a pressure of 50 kg/cm^2,and after 28 days of humid curing at ambient temperature, good quality bricks can be produced. The compressive strength of the bricks has been reported to be in the range of 80–150 kg/cm^2. It was concluded that theproduction of slag based bricks consumes less energy compared to conventional burnt clay bricks or calcium silicate bricks.

The research work by ***PaiHaung-Shih [6]*** investigated into the characteristics of bricks made from steel slag. The ROC national standard CNS 3319 third-class brick for builders has been mentioned. It has been observed that slag addition reduced the required firing temperature. It was mentioned that the ROC national standard CNS 3319 third-class brick for builders was met when the firing temperature was greater than 1050^0C and the slag addition less than 10% the bricks met.It has been suggested that the percentage of slag increased as the quartz and kaolin decreased in the sintered samples while the magnesium aluminium silicate and calcium silicate increased. The XRD analysis conducted in the work did not reveal any new crystal phases in the sample.

The work by ***Torres et.al [7]*** concerns with the use of granite wastes in the form of sludge, obtained from granite cutting industry.On incorporationand subsequent characterization of granite wastes into the batch formulations of porcelain tiles it has been observed that extruded bars or pellets with water absorption of 0.07% and bending strength greater than 50 MPa can be produced. The maximum possible substitution of sludge for feldspar hasalso beeninvestigated. The experimental analyses have shown that with suitable granite sludge incorporation porcelain tiles with superior properties can be produced. It was reported that sludge incorporation had negligible effect on density, shrinkage and plasticity during all stages of tile-production process, anticipating no modifications in the industrial production line.

The granite waste from an industry of stone sawing operations located in the municipal area of Santo Antônio de Pádua, State of Rio de Janeiro, Brazil has been used by ***Vieira et.al [8]***to study the effect of granite powder waste incorporation in a red ceramic body. The work has characterized the granite sawing waste in terms of chemical composition, particles size distribution and X-ray diffraction.Clay mixtures with 0, 10, 20, 30 and 40 wt. % of granite waste have been utilised to fabricateextruded red ceramic specimens which have then been fired at 970^{0}C. It has been reported that the specimens were characterizedfor water absorption, linear shrinkage,three point bending flexural strength, microstructural analysis, phase analysis and porosity. The results have indicated that granite waste presents favourable characteristics for addition into red ceramics.The conclusions have been based on the premise that there has been an observed decrease in porosity.

Naga et.al [9]studied the use of natural granite to completely replace both feldspathic and inert components of a traditional ceramic body. Raw material from Sinai (Egypt) have been added (in the range 20‑35 wt%) to commercial Egyptian ball clays (from Aswan, Egypt) and laboratory tiles sintered at 1220^{0}C have been obtained. Tiles have been characterized on densification, sinterability by optical dilatometry, chemical and physical analysis. Microstructural analysis has revealed a relationship between the phases and microstructure of the tiles. Moderate values for thermal expansion and bending strength have been reported. The work recommended the use of the above batches for the production of ceramic tiles.

OBJECTIVE

Waste utilization is of paramount importance because the limitation on the number of dumping landfill sites and the general disposal methods has rendered the environment unfriendly. A huge quantity of blast furnace slag and granite waste, which contains harmful substances, is of major importance. Present study aims to develop acid resistant bricks using these materials. The objectives of the present study have been outlined below:

1. Formulation of acid resistant bricks using blast furnace slag and granite saw waste.
2. Preparation of samples to study the effect of these raw materials on properties of the bricks.

CHAPTER 4
EXPERIMENTAL PROCEDURE

4.1 POWDER PREPARATION

The raw materials that were used in sample preparation for the production of acid resistant bricks are

- China Clay
- Blast Furnace Slag
- Granite

The samples were prepared with varying compositions of the raw materials as in table I.

Table I: Acid resistant brick formulations

Raw Materials	Weight (%)											
Clay	40					50				60		
Blast Furnace Slag	10	20	30	40	50	10	20	30	40	10	20	30
Granite	50	40	30	20	10	40	30	20	10	30	20	10

The three raw materials were ground into fine powder form and mixed in different proportions to obtain different ratios of the samples. The samples were then pressed into pellets with the help of additives and fired at three different temperatures i.e. 1050°C, 1100°C and 1150°C. The different fired compositions were studied for different characterizations.

4.1.1 PREPARATION OF GRANITE POWDER

The Granite blocks were broken into smaller pieces with a help of a hammer. The broken small pieces were passed through a Jaw Crusher to obtain pieces of about 2-3 inches. Pieces of about 2-3 inches are required because larger pieces cannot be used for ball milling. The Granite pieces were then ball milled in order to get fine powder.

After ball milling, granite powders were passed through a 200 mesh (0.074mm). A few amount of granite powder was ground in a mortar pestle and taken in for Chemical Analysis.

4.1.2 PREPARATION OF BLAST FURNACE SLAG DUST

The Blast Furnace Slag was ball milled. After milling, slag powders were passed through a 200 mesh (0.074mm). Blast Furnace Slag powder was ground in a mortar pestle and taken in for Chemical Analysis.

4.2 SAMPLE PREPARATION

Powders were dry mixed in different compositions to make a dry mix. The batches were dry mixed in a mortar pestle to ensure homogenisation.

Pellets of each batch were prepared by uniaxial pressing at 970.8 kg/cm^2. Pellets were oven dried at 80°C/24 hours.

The pellets were then fired in a furnace at 1050°C, 1100°C and 1150°C with a soaking time of 4 hours. The fired pellets were then characterised for Apparent Porosity, Water Absorption, Firing Shrinkage, Bulk Density, Dimetral Compressive Strength and Acid Mass Loss.

4.2.1. FLOW CHART OF THE PROCESSES INVOLVED

Processing and different characterization steps involved in this study are shown in the Fig 4.1.

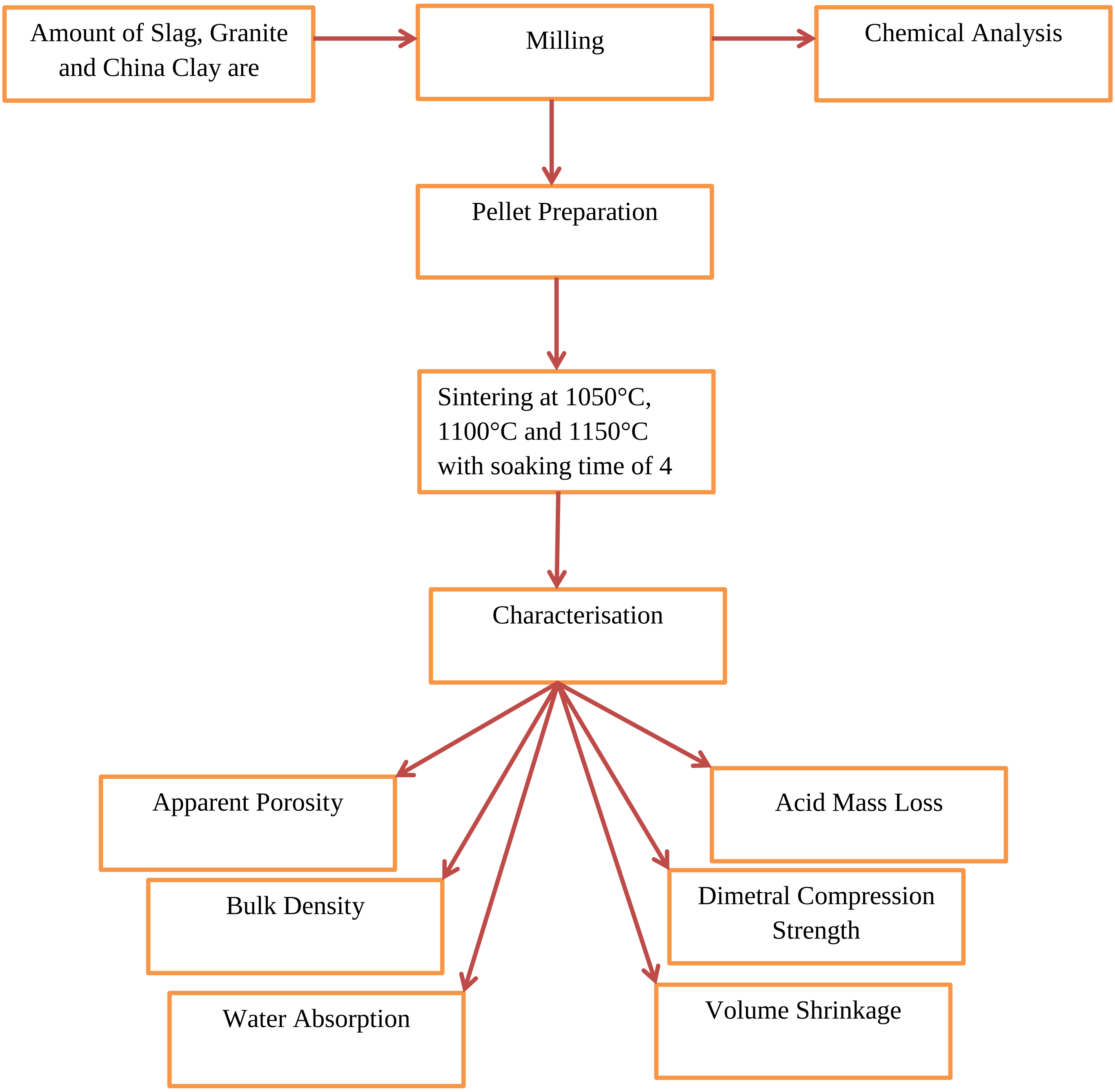

Fig 4.1 Flowchart for the sample preparation

4.3 CHEMICAL ANALYSIS

Chemical analysis requires the presence of samples in talc like state (powdery). An Agate Mortar was taken and the sample (about 1 gram) was ground in it. Granite powder and Blast Furnace Slag were ground out in an agate mortar.

Granite Sample – 0.463 gram

Blast Furnace Slag Sample – 0.483 gram

Wet Chemical method was followed for chemical analysis wherein Na_2CO_3, NaOH fusion was done to fuse in a muffle furnace at1000^{0}C/1 hour. The fused mass was made soluble by using 1:1 HCl solution. Silica was determined by Gravimetric Technique. CaO and MgO were calculated by titration.

4.4 FIRING SHRINKAGE

The dimensions of the sample prior to firing were measured and the volume of the pellets was calculated. After firing the dimensions of the pellets was measured again and the volume of the pellet was found out.

$$\text{Firing Shrinkage (\%)} = \frac{Vi - Vf}{Vi} \text{x } 100 \qquad (4.1)$$

Vf = Volume after firing

Vi = Initial volume

4.5 APPARENT POROSITY

Apparent Porosity (A.P) was calculated for the following samples using the Archimedes' principle. The weights of the sintered products were taken (dry weight, D) and then this was followed by soaking the samples in water. Soaking was done by Vacuum method.The weight of the samples suspended in water(S) was noted. Soaked weight (W) of the samples was measured after removing the surface water. AP has been aculated using the formula given below:

$$\text{A.P.} = \frac{W - D}{\mathrm{W-S}} \qquad (4.2)$$

W = Soaked Weight

D = Dry Weight

S = Suspended Weight

4.6 BULK DENSITY

Bulk Density (B.D) was calculated for the following samples using the Archimedes' principle. The weights of the sintered products were taken (dry weight, D) and then this was followed by soaking the samples in water. Soaking was done by Vacuum method.The weight of the samples suspended in water was taken (suspended weight, S) after which the soaked weight (W) of the samples was measured.

$$B.D. = \frac{D}{\mathrm{W-S}} \qquad (4.3)$$

W = Soaked Weight

D = Dry Weight

S = Suspended Weight

4.7 WATER ABSORPTION

Water Absorption (W.A) was calculated for the following samples using the Archimedes' principle. The weights of the sintered products were taken (dry weight, D) and then this was followed by soaking the samples in water. Soaking was done by Vacuum method.The weight of the samples suspended in water was taken (suspended weight, S) after which the soaked weight (W) of the samples was measured.

$$W.A. = \frac{W - D}{\mathrm{D}} \qquad (4.4)$$

W = Soaked Weight

D = Dry Weight

S = Suspended Weight

4.8 DIMETRAL COMPRESSIVE STRENGTH

In this the pellet is kept in such a way that it can roll along its thickness. The pellet is made to stand and pressure is applied to it, and the force at which it breaks or cracks is noted down. However prior to it, the thickness and the diameter are measured and noted down. To find the compressive strength we use the formula:

$$Dimetral\ Compression\ Strength = \frac{2 \text{ x } \mathrm{P}}{\pi x\ d\ x\ t} \qquad (4.5)$$

P = Load on the material

d = diameter of the sample

t = thickness/height of the sample

4.8 ACID MASS LOSS

10% by volume of HCl was prepared (100 ml) in a beaker. The dry weight of the pellet was noted. The pellets were lowered into the beaker and kept inside the beaker for 24 hours. After 24 hours, the pellets were taken out and the mass noted.

$$\text{Acid mass loss } \% = \frac{Mi - Mf}{Mi} \times 100 \qquad (4.6)$$

Mi = Initial Mass

Mf= Mass after being dipped in acid

CHAPTER 5

RESULTS AND DISCUSSION

5.1 APPARENT POROSITY

Figure 5.1 depict the variation of apparent porosity of the samples as a function of Grantite:Slagratio and sintering temperature, wherein samples prepared with (a) 40% clay, (b)50% clay, (c) 60% clay and (d) samples sintered at 1100^{o}C as a function of clay content.

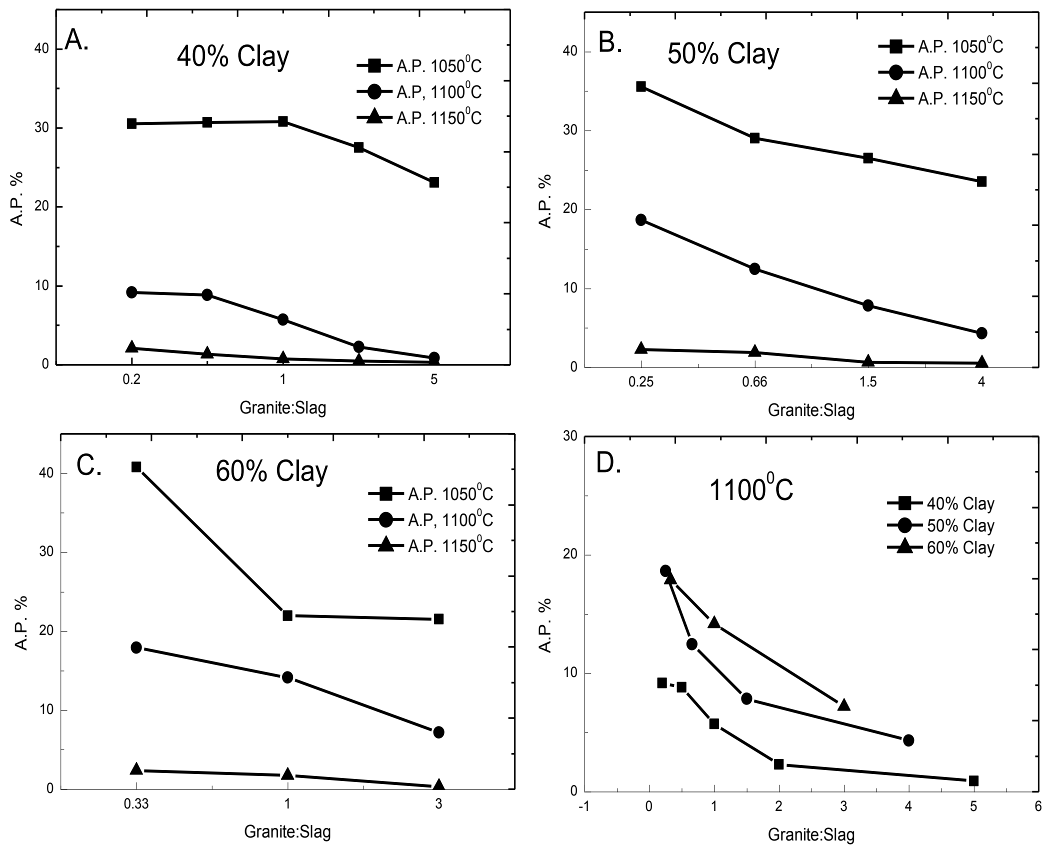

Fig 5.1 Variation of Apparent Porosity of the samples as a function of Granite:Slag ratio and sintering temperature (a) 40% clay, (b) 50% clay, (c) 60% clay and (d) samples sintered at 1100^{o}C as a function of clay content

It could be observedfrom the figurethat with increase in the firing temperature apparent porosity was found to decrease for all the samples studied. It can also be observed that increase in the granite content decreases the apparent porosity of the samples. Granite is consists of three minerals namely feldspar, mica and quartz. The increase in granite content corresponds to an increase in the amount of feldspar, mica and quartz. Feldspar is well known as a fluxing agent in whiteware bodies. It produces liquid phase at a low temperature and helps in vitrification of whiteware body. Thus, increase in granite content leads to an enhanced vitrification of the samples. As a result, the apparent porosity decreases.

It could be seen from Fig. 5.1 (d) that the apparent porosity of the samples prepared with high amount of clay is higher as compared to that prepared with low amount of clay. The amount of granite in the sample for fixed granite to slag ratio is small in the samples having high amount of clay as compared to that prepared with low clay. Thus, the samples prepared with high clay content showed a high apparent porosity.

Figure 5.2 depict the variation of apparent porosity of the samples as a function of Grantite:Slag ratio and sintering temperature, wherein samples prepared with (a) 40% clay, (b) 50% clay, (c) 60% clay

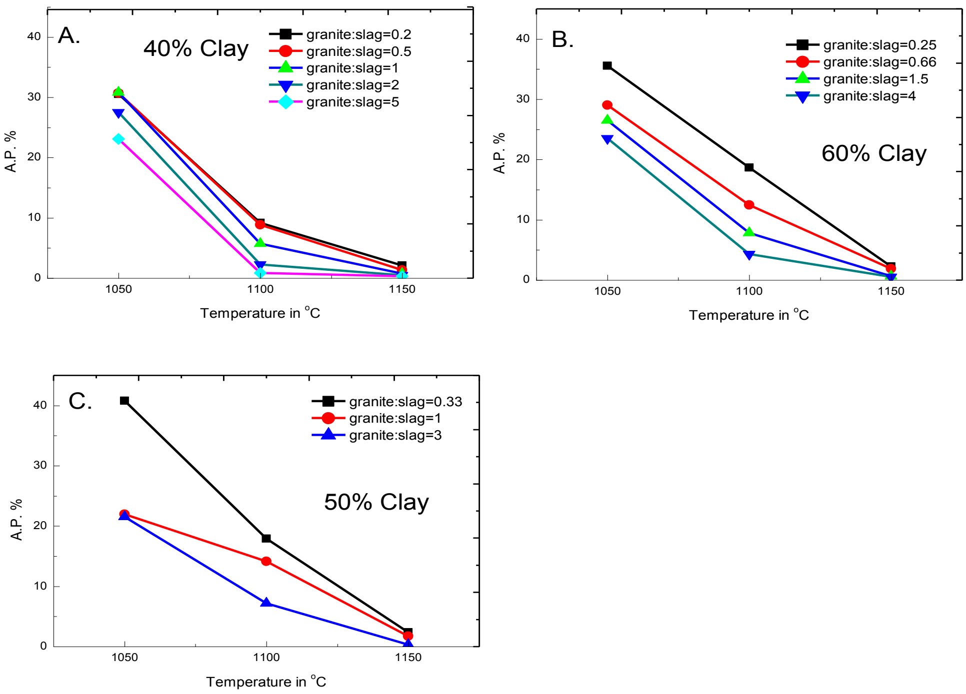

Fig.5.2 Variation of apparent porosity of the samples as a function of Granite:Slag ratio and sintering temperature (a) 40% clay, (b) 50% clay and (c) 60% clay

It could be observed from the figure that with increase in the granite content the apparent porosity was found to decrease for all the samples studied. It can also be observed that increase in the temperature decreases the apparent porosity of the samples. Feldspar is well known as a fluxing agent, which aids in liquid phase formation at low temperature. Vitrification is thus helped by the incorporation feldspar from the granite in the body formulation. Granite is known to consist of three minerals namely feldspar, mica and quartz. The increase in granite content thus leads to an increase in the amount of feldspar. Thus, increase in granite content leads to an enhanced vitrification of the samples. As a result, the apparent porosity decreases.

5.2 BULK DENSITY

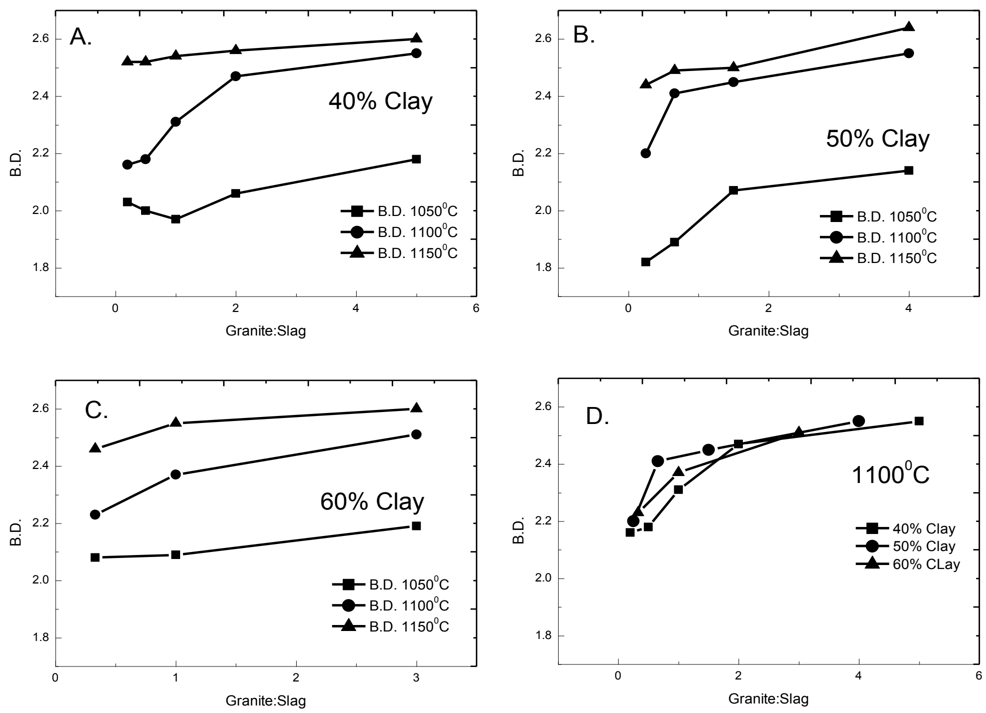

Fig 5.3Variation of bulk density of the samples as a function of Granite:Slag ratio and sintering temperature (a) 40% clay, (b) 50% clay, (c) 60% clay and (d) samples sintered at 1100^{o}C as a function of clay content

Figure 5.3 depict the variation of bulk density of the samples as a function of Grantite:Slag ratio and sintering temperature, wherein samples prepared with (a) 40% clay, (b) 50% clay, (c) 60% clay and (d) samples sintered at 1100^{o}C as a function of clay content.

It could be observed that all the samples studied have an increase in the bulk density values with increase in the firing temperature. It can also be observed that increase in the granite content increases the bulk density of the samples. Feldspar, mica and quartz are three minerals which constitute the granite. The increase in granite content corresponds to an increase in the amount of feldspar in the body formulation.Feldspar in normally incorporated in whiteware bodiesas a fluxing agent, which in turns lower the vitrification range of the body. Enhanced densification of the sampleswith increase in granite content can be correlated with the increase in feldspar content of the body formulation. As the granite content in the boy mix increases it increases the amount of feldspar in body thus the bulk density increases.

It could be seen from Fig. 5.3 (d) that the bulk density of the samples prepared with high amount of clay is lower as compared to that prepared with low amount of clay. The amount of granite in the sample for fixed granite to slag ratio the mount of granite is small in the samples having high amount of clay as compared to that prepared with low clay. Thus, the samples prepared with high clay content showed a low bulk density.

Figure 5.4 depict the variation of bulk density of the samples as a function of Grantite:Slag ratio and sintering temperature, wherein samples prepared with (a) 40% clay, (b) 50% clay, (c) 60% clay.

All the samples studied have been foundto have an increase in the bulk density with increase in the granite content. It can also be observed that increase in the firing temperatureincreases the bulk density of the samples. The three minerals which constitute the granite are feldspar, mica and quartz. The increase in granite content corresponds to an increase in the amount of feldspar, mica and quartz. Whiteware bodies formulations are known to use feldspar as a fluxing agent. Feldspar aids in the production of liquid phase at a low temperature and in vitrification of whiteware body. Enhanced vitrification of the samples can be thus attributed to increasing granite content. As a result, the bulk density increases.

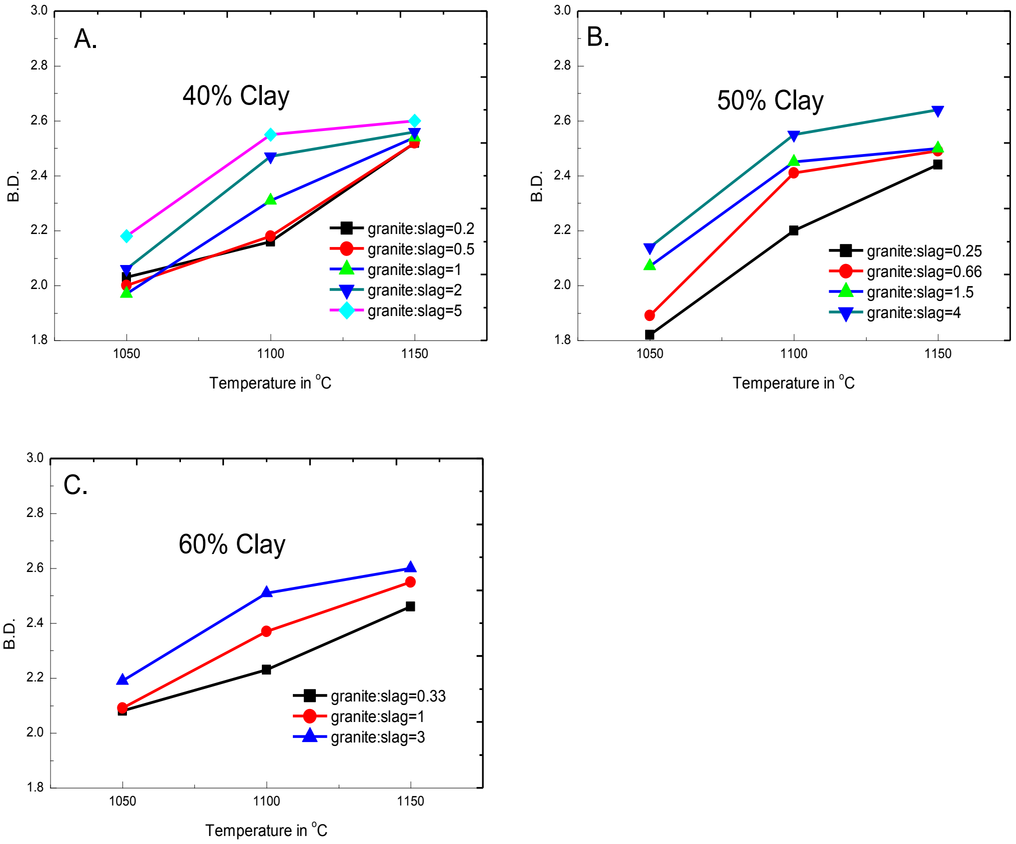

Fig.5.4 Variation of bulk density of the samples as a function of Granite:Slag ratio and sintering temperature (a) 40% clay, (b) 50% clay and (c) 60% clay

5.3 WATER ABSORPTION

Figure 5.5 depict the variation of bulk density of the samples as a function of Grantite:Slag ratio and sintering temperature, wherein samples prepared with (a) 40% clay, (b) 50% clay, (c) 60% clay and (d) samples sintered at 1100°C as a function of clay content.

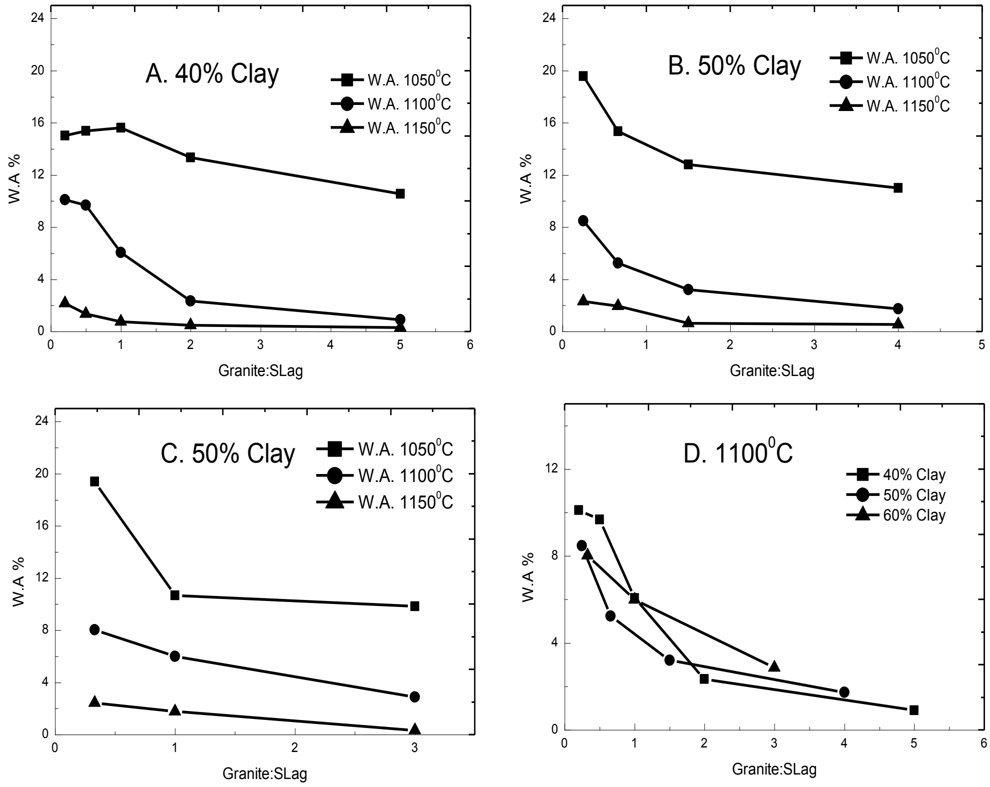

Fig 5.5Variation of water absorption of the samples as a function of Granite:Slag ratio and sintering temperature (a) 40% clay, (b) 50% clay, (c) 60% clay and (d) samples sintered at 1100^oC as a function of clay content

From the figure it could be observed that decrease in Water Absorption occurs with increase in the firing temperature for all the samples studied. The inverse correlation could be observed between the granite content with the water absorption of the samples. Feldspar, mica and quartz are three minerals which constitute the granite. The increase in granite content correlates to an increase in the amount of feldspar in the samples. Feldspar is well known as a fluxing agent, which produces liquid phase at a low temperature and helps in vitrification of whiteware body. Samples with increased vitrification are a direct consequence of the increased granite content. As a result, the water absorption decreases.

Samples prepared with higher amount of clay are observed from Fig. 5.5 (d) to have higher water absorption as compared to that prepared with low amount of clay. For fixed granite to slag ratio the amount of granite in the sample is small in the samples having high amount of clay as compared to that prepared with low clay. Thus, the samples prepared with high clay content showed high water absorption.

Figure 5.6 depict the variation of water absorption of the samples as a function of Grantite:Slag ratio and sintering temperature, wherein samples prepared with (a) 40% clay, (b) 50% clay, (c) 60% clay.

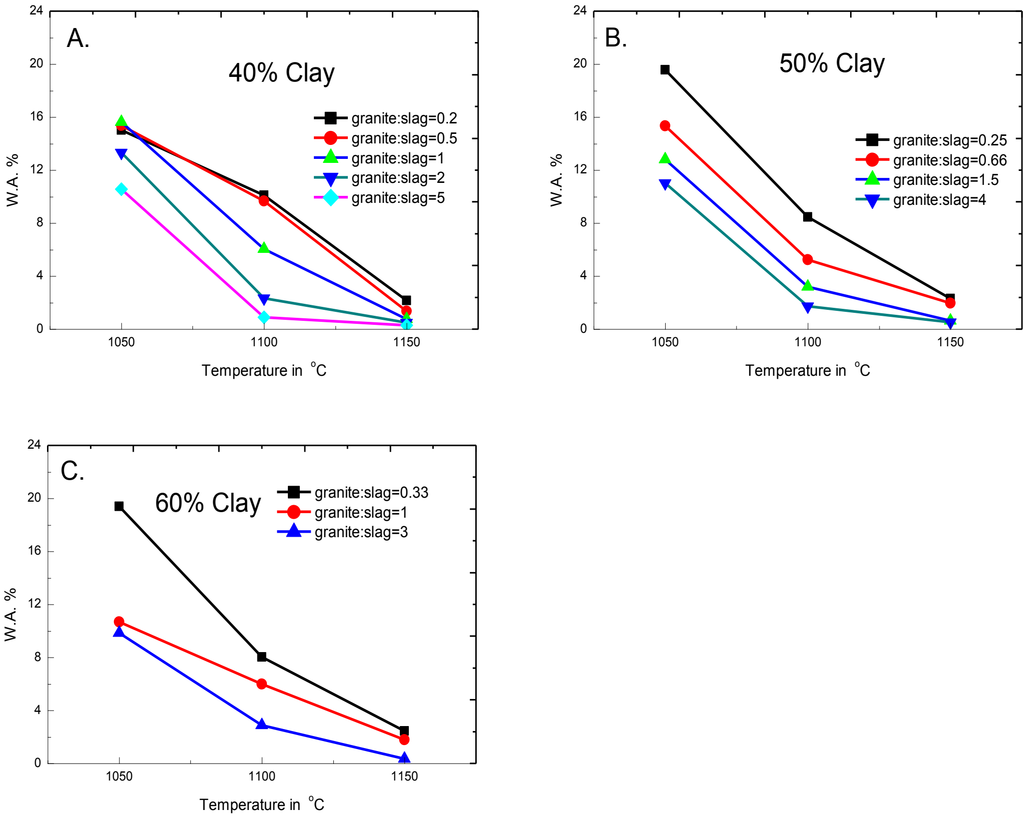

Fig.5.6 Variation of water absorption of the samples as a function of Granite:Slag ratio and sintering temperature (a) 40% clay, (b) 50% clay and (c) 60% clay

From the figure it could be observed that decrease in the values of Water Absorption took place with increase in the granite content for all the samples studied. The inverse correlation could be observed between the firing temperatures with the water absorption of the samples. Feldspar, mica and quartz are three minerals which constitute the granite. The increase in granite content corelates to an increase in the amount of feldspar, mica and quartz. Feldspar is well known as a fluxing agent which produces liquid phase at a low temperature and helps in vitrification of whiteware body. Samples with increased vitrification are a direct consequence of the increased granite content. As a result, the water absorption decreases

5.4 VOLUME SHRINKAGE

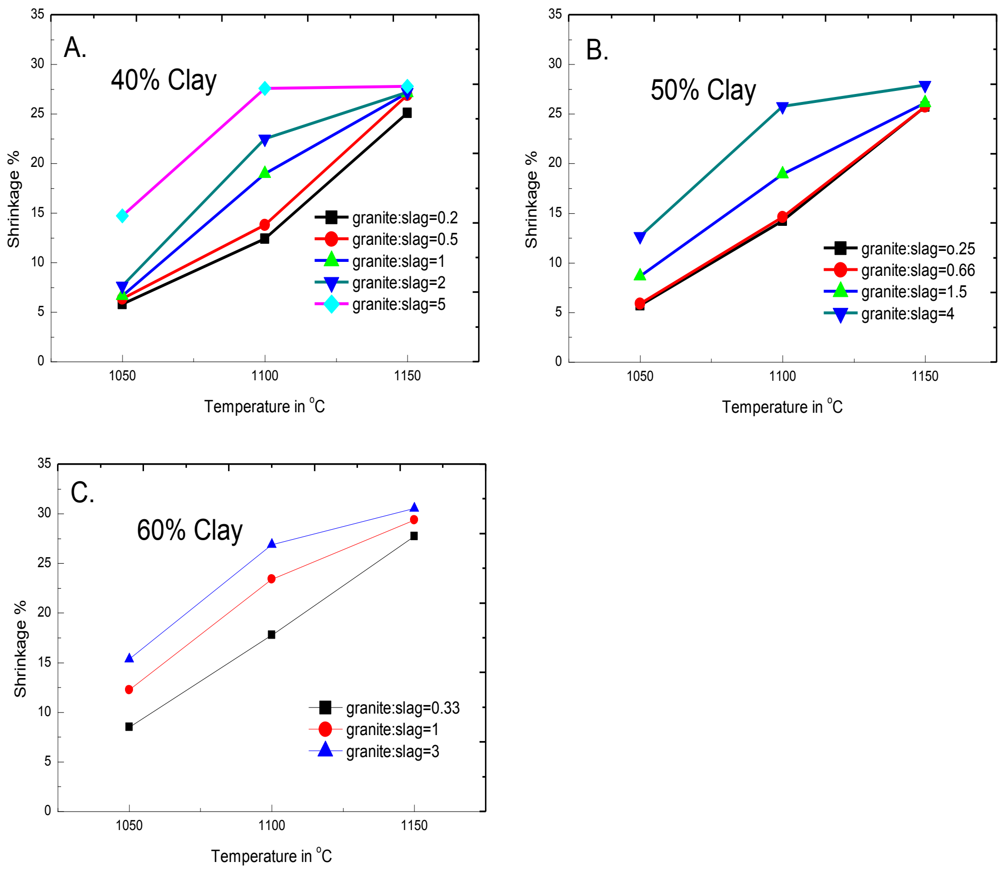

Fig.5.7 Variation of volume shrinkage of the samples as a function of Granite:Slag ratio and sintering temperature (a) 40% clay, (b) 50% clay and (c) 60% clay.

Figure 5.7 depict the variation of volume shrinkage of the samples as a function of Grantite:Slag ratio and sintering temperature, wherein samples prepared with (a) 40% clay, (b) 50% clay, (c) 60% clay.

All the samples studied have been reportedto have an increase in the shrinkage values with increase in the granite contentfrom. It can also be observed that increase in the firing temperatureincreases the bulk density of the samples. The granite mineral consists of Feldspar which is used as a fluxing agent in the whiteware industry. It helps to attain better densification and thus shrinkage is observed. With increasing granite content the feldspar content increases. Enhanced vitrification of the samples can be thus attributed to increasing granite content .As a result, shrinkage is increases.

5.5 MASS LOSS

Figure 5.8 depicts the variation Acid resistance of the samples as a function of Granite:Slag ratio and clay amount in the body formulation samples sintered at 1150^{o}C

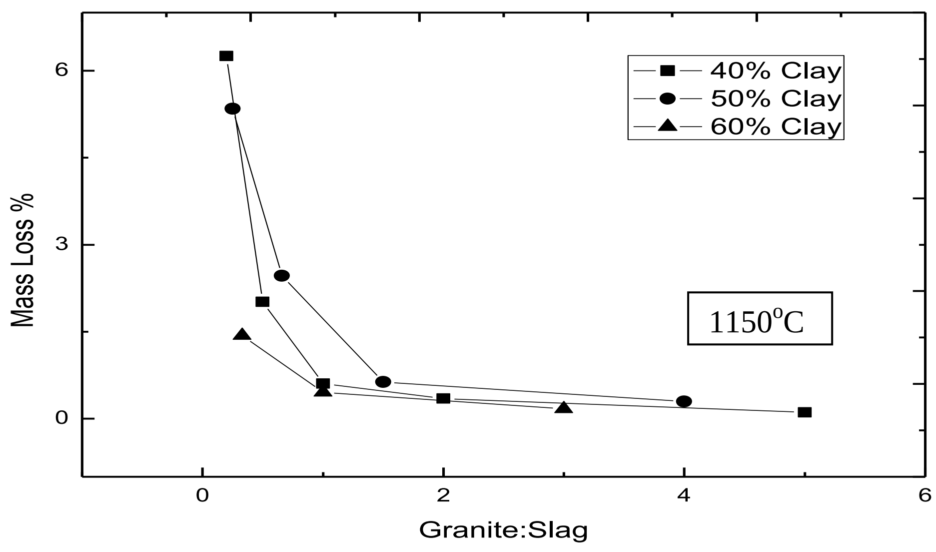

Fig 5.8 Acid resistance of the samples as a function of Granite:Slagratio and clay amount in the body formulation samples sintered at 1150^{o}C

From the figure it could be observed that the mass loss % decreases with increase in granite content for 40% clay, 50% clay and 60% clay. It is observed that the porosity of the samples is more when formulated with low granite to slag ration. However it decreases with the increase in granite to slag ratio irrespective to the clay content in the formulation. The sample surface area exposed to the acid solution is expected to increase with the porosity of the sample. Dissolution of brick into the acid solution will increase with the increase in exposed area of the sample. Hence the samples prepared with low granite:slag ratio showed higher dissolution as compared to that prepared with high granite to slag ratio.

5.6 DIMETRAL COMPRESSIVE STRENGTH

Figure 5.9 reports the variation of strength of the samples as a function of Granite:Slag ratio and clay amount in the body formulation samples sintered at 1150^{o}C.

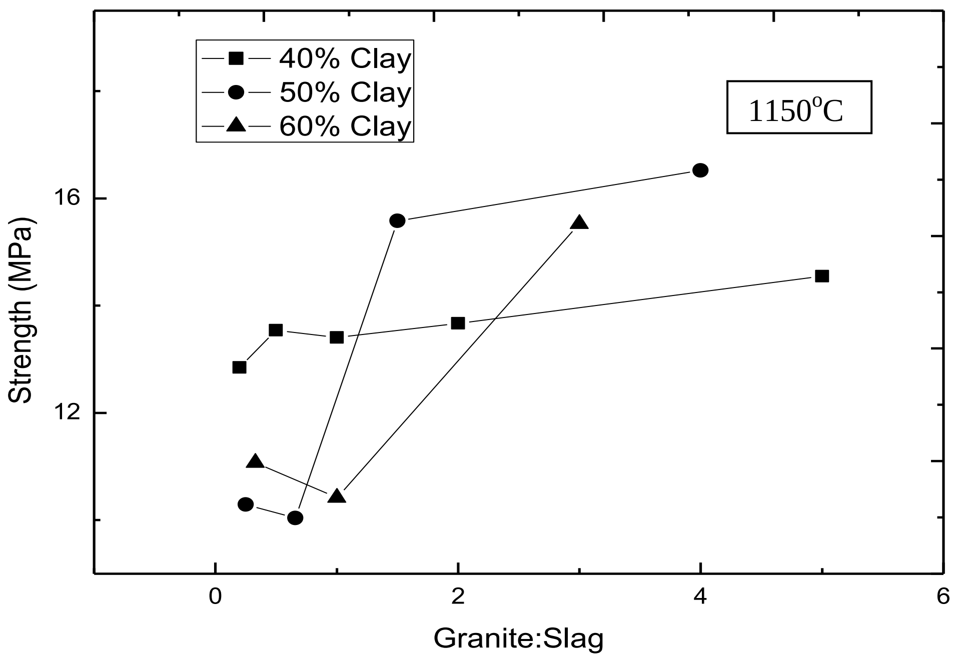

Fig 5.9 Strength of the samples as a function of Granite:Slag ratio and clay amount in the body formulation samples sintered at 1150^{o}C.

Strength values of all the samples are found to be quite high in the range of 10 to 15 MPa. This higher value can be attributed with the achievement of enhanced vitrification in the sample. It is interesting to note that these measured strength values does not show any particular trend as a function of granite;slag ratio or the clay content in the body. These values might have been overorunder estimated as the experiments had been carried out with only one sample.

CONCLUSION

The experimental results carried out during the present work wold lead to the following conclusion.

- ✓ The samples with higher granite content found to be vritrified completely and could be correlated with the granite content of the sample.
- ✓ The samples with Water Absorption <2%, and Acid Mass Loss <1.5% confirm to the IS 4860-1968 to be used as acid resistant brick. The study suggests that body formulations with Clay-Granite-Slag ratio as 40-30-30, 40-40-20 and 40-50-10; 50-30-20 and 50-40-10; 60-30-10 has a potential to be used as acid resistance bricks.

FUTURE WORK

The results embedded in this present work and the analysis of the experimental data suggests carrying out the following work to make the technology commercially viable.

- ✓ Synthesis of pellets to conduct tests ofdimetral compressive strength.
- ✓ XRD analyses of the samples to study detailed phase formation behaviour.
- ✓ Synthesis of larger samples to conduct in situ tests on the acid resistant behaviour.

REFERENCE

1. Ibrahim, D.M., Mostafa, A.A., Nour, W.M.N**., ''Granite processing waste as a source of flux for the production of acid resistant sewage bricks''**, InterCeram: International Ceramic ReviewVolume 55, Issue 3, May 2006, Pages 186-190.
2. Romualdo R. Menezesa, Heber S. Ferreirab, Gelmires A. Nevesb, Helio de L. Lirab, Heber C. Ferreirab, **''Use of granite sawing wastes in the production of ceramic bricks and tiles''**, Journal of the European Ceramic SocietyVolume 25, Issue 7, May 2005, Pages 1149–1158.
3. Medhat S. El-Mahllawy, **''Characteristics of acid resisting bricks made from quarry residues and waste steel slag''**, Construction and Building MaterialsVolume 22, Issue 8, August 2008, Pages 1887–1896.
4. D. Eliche-Quesada, C. Martínez-García, M.L. Martínez-Cartas, M.T. Cotes-Palomino, L. Pérez-Villarejo, N. Cruz-Pérez, F.A. Corpas-Iglesias, **''The use of different forms of waste in the manufacture of ceramic bricks''**Applied Clay ScienceVolume 52, Issue 3, May 2011, Pages 270–276.
5. S.K. Malhotra, S.P. Tehri, **''Development of bricks from granulated blast furnace slag''**Construction and Building MaterialsVolume 10, Issue 3, April 1996, Pages 191–193.
6. Pai-Haung Shih, Zong-Zheng Wu, Hung-Lung Chiang**, ''Characteristics of bricks made from waste steel slag''**Waste ManagementVolume 24, Issue 10, 2004, Pages 1043–1047.
7. P Torres, H.R Fernandes, S Agathopoulos, D.U Tulyaganov, J.M.F Ferreira, **''Incorporation of granite cutting sludge in industrial porcelain tile**

formulations''Journal of the European Ceramic SocietyVolume 24, Issues 10–11, September 2004, Pages 3177–3185.

8. Vieira, C.M.F., Soares, T.M., Sánchez, R., Monteiro, S.N., **''Incorporation of granite waste in red ceramics''**Materials Science and Engineering AVolume 373, Issue 1-2, 25 May 2004, Pages 115-121
9. H.F. El-Maghrabya, Mohamed M. El-Omlab, F. Bondiolic, S.M. Nagaa, '**'Granite as flux in stoneware tile manufacturing''**Journal of the European Ceramic SocietyVolume 31, Issue 12, 15 October 2011, Pages 2057–2063